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## (54) Alkylation process with enhanced catalyst stability

(57) A process for alkylating aromatic substrates using a pentasil type catalyst is disclosed wherein the catalyst is stabilized by the presence of water. An aromatic substrate, such as benzene, is reacted with an alkylating agent, such as ethylene, over a pentasil type catalyst, including ZSM-5 and silicalite types. The aromatic feedstock may be used without drying to remove water in the process of the present invention. It has been heretofore necessary to remove water from the feedstock by, for instance distillation, since even trace amounts of water had been found to markedly degrade many catalysts of the pentasil type. The process of the present invention discloses the use of pentasil catalysts for alkylation in the presence of 100-100,000 ppm water to yield enhanced catalyst stability.

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**Description****TECHNICAL FIELD OF THE INVENTION**

5 This invention relates to a press for the alkylation of aromatic compounds using a pentasil type catalyst wherein the stability of the catalyst is enhanced by the addition of water to the reaction zone.

**BACKGROUND OF THE INVENTION**

10 Alkylaromatic compounds, such as ethylbenzene, ethyl toluene, isopropylbenzene and the like are very important as precursors in the manufacture of vinylaromatic monomers. The resulting vinylaromatic monomers are used to make a variety of useful polymer materials, styrenic resins for example. In a typical commercial process, alkylaromatic compounds are produced by catalytic alkylation at elevated temperatures.

Developments in the catalysts employed in the above-referenced alkylation process have improved the efficiency  
 15 of the commercial manufacture of alkylaromatic compounds. One group of particularly effective catalysts is that of the pentasil materials. Pentasils, including the ZSM-5 and silicalite type zeolites, are examined in detail by Debras et al. in "Physico-chemical characterization of pentasil type material, I. Precursors and calcined zeolite, and II. Thermal analysis of the precursors", *Zeolites*, 1985, Vol. 5, pp 369-383. Both silicalite and ZSM-5 type catalysts can be characterized very generally in terms of mole oxide ratios as follows:



Wherein:

M is an alkali metal cation, normally sodium

25 x is the mole ratio of alkali metal oxide to alumina, and

y is the silica/alumina ratio.

Although both silicalite and ZSM-5 zeolites are categorized as pentasils, the ZSM-5 materials are characterized as  
 30 aluminosilicates as disclosed in U.S. Patent No. 3,702,886 to Argauer et al. or as metal organosilicates as disclosed in Re 29,948 to Dwyer (high silica/alumina ratio). Silicalites, on the other hand, are described in U.S. Patent No. 4,061,724 to Grose et al. The silicalite type pentasil contains minor amounts of aluminum as a impurity only. The aluminum content of a silicalite is less than one aluminum atom for each unit cell of 96 SiO<sub>2</sub> tetrahedra. Thus, silicalite has a silica/alumina ratio of about 200 or more. Debras et al., *supra*, details several differences between the two materials, including differences in structure and synthesis procedure.

One problem encountered in alkylation processes using a catalyst is that the catalyst loses its ability to promote alkylation over time. That is, over time the catalyst alkylates progressively less and less of the aromatic feedstock. The alkylation unit must be finally shut down and the catalyst regenerated or replaced, at substantial expense to the chemical manufacturer. This loss of catalytic activity is thought to be due to the build-up of long chain polymers on the surface  
 40 and in the pore structure of the catalysts. This build-up of polymers is commonly referred to as "coking".

Although the pentasil type catalysts have improved alkylation/transalkylation characteristics, coking remains a problem in alkylation processes employing them. In particular, it has been widely noted that even small amounts of water produce the degeneration of the ZSM-5 type catalysts. (See, for example U.S. Patent No. 4,387,260 to Watson et al., U.S. Patent No. 4,490,570 to Forward et al., and U.S. Patent No. 4,559,314 to Shihabi). It is generally believed that  
 45 water progressively dealuminates the framework of the zeolite crystals, irreversibly deactivating it. Common industrial procedure calls for aromatic feedstock to be subjected to a dehydrating procedure prior to initiation of the alkylation process when ZSM-5 catalyst is used.

On the other hand, U.S. Patent No. 4,387,260 to Watson et al. discloses the alkylation of aromatic compounds over silicalite catalyst wherein a water cofeed is supplied, preferably with in the range of 20,000-60,000 ppm water. U.S. Patent Nos. 4,774,379 to Butler et al. and 4,387,260 to Watson et al. also disclose alkylation processes in which water is added to extend the effective life of a silicalite catalyst. It should be noted, however, that in the case of the steam co-feed disclosed in U.S. Patent No. 4,387,260 the catalyst ages are reported in hours, and some catalyst degradation was reported as the steam was co-fed.

Thus, improved alkylation processes are needed that give enhanced stability of pentasil catalysts over time.

55

**SUMMARY OF THE INVENTION**

In accordance with the present invention, there is provided a process for the alkylation of aromatic substrates by

alkylating agents using pentasil type catalysts in which water is co-fed to the reaction zone at concentrations from 100 - 60,000 ppm to enhance catalyst stability. Tests with a silicalite catalyst having a crystal size within a specified range showed catalyst stability levels superior to those reported in the previous references *supra*. In the case of the tests with ZSM-5 catalyst, the resulting enhanced catalyst stability was a great surprise since it contravenes all previous teaching regarding the deleterious effect of water on ZSM-5 catalyst. As a result of the process of the present invention, it is no longer necessary to dry the aromatic feed prior to alkylation over pentasil catalysts; a discovery resulting in significant cost savings in plant operation.

To carry out the process of the present invention, the aromatic feedstock and water are supplied to a reaction zone and brought into contact with a pentasil type catalyst. An alkylating agent is also supplied to the reaction zone which is preferably operated under temperature and pressure conditions to maintain the aromatic substrate in the vapor phase

The operating conditions are selected to promote the alkylation of the aromatic substrate in the presence of the pentasil catalyst, including a temperature of from about 250°C to about 500°C and 200 psig to 500 psig pressure.

A preferred application of the present invention is the alkylation of benzene with ethylene to produce ethylbenzene. The process is preferably carried out in the vapor phase. The process of the present invention may be carried out in a multiple bed reactor wherein there is a stoichiometric excess of benzene supplied to the reactor relative to the ethylene concentration. In the preferred embodiment, the reactor effluent is subjected to successive fractionations to separate benzene, ethylbenzene, polyalkylated compounds and heavy residues into separated streams. The ethylbenzene product may be recovered after separation.

The stream of polyalkylated compounds is directed to a separate transalkylation reactor or is recycled to the alkylation reactor for transalkylation into the desired monoalkylated product simultaneous with the alkylation of the aromatic feedstock.

In one embodiment of the present invention, the catalyst comprises a silicalite characterized as 70-100% monoclinic and 0-30% orthorhombic silicalite formulated with 10-0% refractory oxide binder. Alumina has been found to be a suitable binder. The silica/alumina ratio is 50-500 and the average crystal size less than 0.50 microns. The catalyst is further characterized by a maximum pore size of the refractory oxide binder of 1000-1800 Angstroms and a sodium content of the silicalite of less than about 50 ppm.

#### BRIEF DESCRIPTION OF THE DRAWINGS

- 30 FIGURE 1 is a schematic representation of the process of the present invention;
- FIGURES 2-5 are graphical representations showing experimental results from co-feeding 3% steam to ZSM-5 catalyst;
- 35 FIGURES 6-8 are graphical representations of the performance of the ZSM-5 catalyst of FIGURES 2-5 after regeneration;
- FIGURES 9-11 are graphical representations showing experimental results of co-feeding 3% steam to a silicalite catalyst with reduced particle size; and
- 40 FIGURE 12 is a graphical representation of the effect of low concentrations of water in the feedstock on conversion.

#### DETAILED DESCRIPTION

45 The process of the present invention can be carried out using a variety of process equipment, including a reactor vessel which defines a reaction zone containing catalyst material. Either single or multiple catalyst beds may be employed in the reaction zone. In the case wherein benzene is alkylated with ethylene to produce ethylbenzene, the ethylene and benzene reactants may be mixed and preheated prior to introduction to the reaction zone. The reaction zone may consist of one or more catalyst beds where the reactants contact the catalyst under reaction conditions. The reaction products are withdrawn from the reaction zone after a controlled residence time and then collected and separated by conventional techniques.

50 Products of the alkylation reaction include ethylbenzene, unreacted benzene, polyalkylated aromatics and heavy residue. Excess benzene along with polyalkylaromatics are typically recycled to the reaction zone and the heavy residue withdrawn as a purge stream. In the alternative, the polyalkylaromatics may be directed to a separate transalkylation reactor where they are broken down into ethylbenzene.

55 The catalysts used in the process of the present invention are selective to the production of ethylbenzene in a temperature range of from about 250°C to about 500°C and a pressure range of from about 200 psi to about 500 psi. The alkylation reaction is exothermic, resulting in a positive temperature differential from the reactor inlet to the reactor outlet

of about 20°-100°C.

The mole ratio of alkylating agent to the alkylatable aromatic substrate may be varied in accordance with the desired reaction product. Normally, a substantial stoichiometric excess of aromatic feedstock relative to the alkylating agent will be employed. For example, when ethylene is employed in the alkylation of benzene to produce ethylbenzene, the mole ratio of the alkylatable substrate to ethylene should be within the range of 2:1-20:1 benzene to ethylene. In any case, there should be a substantial stoichiometric excess of the alkylatable substrate.

Another critical factor in alkylation/transalkylation reactions is the time that the reactants are in contact with the catalyst bed, expressed as space velocity. The space velocity based upon the alkylatable substrate will normally be within the range of 30-200 hours<sup>-1</sup>. Further description of the process parameters and procedures which may be employed in the alkylation of aromatic compounds in accordance with the present invention may be found in U.S. Patent No. 4,744,379 to Butler et al.

Referring now to FIGURE 1, an example of a process design suitable for performing an alkylation/transalkylation reaction according to the process of the present invention can be seen. A feed stream containing aromatic hydrocarbons such as benzene is typically passed through drying column 40. The benzene can contain as much as 700 ppm water, but current industry standards demand that the maximum water content of the aromatic feed stock comprise less than 50 ppm water. Typically, the drying column 40 separates the water and the benzene by distillation, although other methods of drying feed stock are possible.

An alkylating agent, such as ethylene, is co-injected into the reactor containing multiple beds of catalyst 12. Since the alkylation reaction is highly exothermic, the reactants may be injected at multiple locations in the reactor for process control purposes. An effluent stream 14 from the reactor 10 is directed to one or more benzene fractionating columns 16 where benzene is separated from the reactor effluent. The overhead stream 18 from the benzene fractionating column is recycled to the feed stream 8 and to the alkylation reactor 10. The bottom stream 20 from the benzene fractionating column 16 is directed to an ethylbenzene fractionating column 22 where an ethylbenzene product stream 24 is separated and recovered. The bottom stream 26 from the ethylbenzene fractionating column is directed to a third fractionating column 28 where an overhead stream 30 containing polyalkylated aromatics, is separated and recycled to the alkylation reactor for transalkylation. This recycled polyalkylated aromatic stream may contain for example, di- and triethyl benzenes, xylenes, styrene, cumene and propyl benzene. Alternately, the polyalkylated aromatic stream may be directed to a separate transalkylation unit (not shown).

Higher boiling point residual materials are purged from the third fractionating column 28 in purge stream 32. The purge stream may contain such compounds as naphthalene, di- and tri-phenyl methane and ethane, and other heavier aromatic compounds.

Pentasil materials, notably ZSM-5 and silicalite type zeolites have been found to be suitable catalysts for the alkylation/transalkylation process. While structurally similar, the catalysts also display significant differences as has been discussed above. One of the most important differences has been thought to be the widely reported sensitivity of ZSM-5 type catalyst to even very small amounts of water. Applicant has investigated alkylation/transalkylation processes using both silicalite and commercially available ZSM-5 catalysts with the surprising result that when used in the above-described process, the stability of neither catalyst was deteriorated by the addition of water to the process. The stability was, to the contrary, increased. As used in this application, stability shall be understood to mean the ability of the catalyst to convert feedstock to desired products measured as a function of time during which the reactions proceed.

The silicalite catalysts employed in the present invention are formulated with a refractory oxide binder in accordance with conventional practice. Here, however, the refractory oxide binder has a somewhat larger pore size than is associated with binders commonly used to form molecular sieve catalyst particles. Specifically, the maximum pore size of the binder used in incorporating the silicalite catalyst into the catalyst particles has a maximum pore size of about 1,000-1,800 angstroms. The molecular sieve silicalite itself preferably has an average crystal size of about 0.5 microns or less. The silicalite crystal structure will normally exhibit a pore size of about 5 to 6 angstroms and normally no more than 7 angstroms.

A preferred refractory binder for use in the present invention is alumina having an average maximum pore size within the range of about 1,000-1,800 angstroms. While Applicants' invention is not to be limited by theory, it is postulated that by using a binder, such as alumina, of the requisite relatively large pore size, the catalyst is allowed to function without the binder imposing a diffusion-limiting factor as the silicalite is used as the catalyst in the alkylation reaction. In the present invention the catalyst particles themselves may be of any suitable size but typically will have a diameter of 0.3 cm (one-eighth inch). The ZSM-5 catalyst may likewise be formulated with a refractory oxide binder of larger than normal pore size as described above.

In one set of experiments, a substantial amount of water (30,000 ppm) was added to the reactor so that the effect of the addition of the water could be rapidly and clearly ascertained. Table 1 shows the operational parameters used in Examples detailed below. As is shown in Table 2, the ZSM-5 catalyst continued to effectively catalyze the alkylation reaction after the addition of substantial amounts of water to the reaction. This is a surprising result and counter to the teachings in the art which clearly state that even small amounts of water rapidly deactivate ZSM-5 catalyst. FIGURE 2

shows temperatures taken at various locations within the reactor vessel. The temperatures remained relatively constant throughout the test period, indicating the on-going exothermic alkylation reaction and no substantial degradation of the catalyst. In particular, no significant change in temperature was seen when the water feed was begun on the second day of the run. FIGURES 3 and 4 show various components of the effluent stream. Xylene is a major contaminant in ethylbenzene production. All of these component concentrations are within expected ranges. FIGURE 5 shows the percent conversion and the selectivity of the process for the production of ethylbenzene. Conversion, for the purposes of this application, is

$$10 \quad \frac{\text{moles of alkylaromatic product} \times 100}{\text{moles of alkylating agent}}$$

The conversion values shown in Example 1 are high and consistent.  
All of these parameters point to stability of the catalyst over time and certainly do not indicate the catalyst degradation that would have been anticipated from the prior art.

In Example 2, the catalyst from Example 1 was regenerated in the usual fashion and retested using the procedure of Example 1 to ascertain the long term effects of water on the catalyst. The composition of the effluent resulting from the test is shown in Table 3. The catalyst returned to approximately the same reaction efficiency as before exposure to the water as shown by the reaction temperature stability of FIGURE 6. Unexpectedly, the ZSM-5 catalyst was not damaged by copious amounts of steam. FIGURE 7 shows the concentration of ethylbenzene and di-ethylbenzenes during the testing period and FIGURE 8 shows the percent conversion and selectivity. All values are within normal ranges.

The same laboratory scale alkylation test runs were performed using a silicalite catalyst that is 70%-100% monoclinic and 0%-30% orthorhombic silicalite. The silica/alumina ratio is 50-500 and the average crystal size is less than 0.50 microns. The catalyst is further characterized by a maximum pore size of the alumina binder of 1000-1800 Angstroms and a sodium content of the silicalite of less than about 50 ppm.

It is taught in the prior art that co-feeding steam to silicalite catalyst prolongs the alkylation cycle between regenerations. U.S. Patent Nos. 4,387,260 to Watson and 4,774,379 to Butler et al. disclose co-feeding steam at concentrations between 10,000 and 100,000 ppm water (1 %-10%) in an alkylation reactor. Some degradation was seen in the reported tests, however, as discussed above.

Table 4 shows the composition of the effluent stream of the laboratory reactor test run with silicalite catalyst. The composition of the alkylation reactor effluent produced by the silicalite catalyst and shown in Table 4 is within acceptable ranges. FIGURE 9 is a graphical representation of the concentrations of ethylbenzene and di-ethylbenzenes over time and FIGURE 10 represents the percent conversion and selectivity. All parameters are within expected ranges.

During the experimental procedure shown in Example 3 the benzene feed was interrupted on day 9 of the test, leaving only ethylene and water over the catalyst. It would be expected that the ethylene would polymerize in the catalyst immediately, causing extraordinary amounts of coking and completely shutting down the laboratory run. Remarkably, after correcting the equipment malfunction, the catalyst performed substantially as well as before the test was interrupted as evidenced by the exotherm seen in FIGURE 11.

Example 4 illustrates the ability of the ZSM-5 catalyst of the present invention to tolerate lower concentrations of water such as are found in benzene feedstock that has not been subjected to a drying process. A plant scale trial was performed using an equipment configuration generally shown in Figure 1. Figure 12 shows that the amount of water in the feedstock has no discernable effect on the percent conversion. The manufacturer has been able to eliminate a water removal step from the alkylation process giving significant cost savings.

The process of the present invention may be further illustrated by the following examples which are not to be construed as limiting the scope of the invention as hereinafter claimed.

#### EXAMPLE 1

Ten milliliters of a commercially available ZSM-5 type catalyst having a particle size distribution of between 20 and 40 mesh is introduced into a laboratory scale reactor. The catalyst had been regenerated four times previous to the present run. The catalyst is heated under nitrogen flow to 150°C overnight at ambient pressure to dry the catalyst. The temperature is increased to 200°C and benzene with about 10% mixed polyalkylated benzenes is introduced to the reactor at a rate of 11.6 ml/min. The pressure is increased to 300 psig and the temperature raised to 400°C. After the temperature across the reactor bed has stabilized, ethylene is introduced at a rate of 1 mole for 10 moles of benzene feed. The reactor was allowed to run at normal conditions for 2 days to obtain baseline conditions. On the second day, the water pump was started for water co-feed at the rate of 0.31 ml/min or 3% by weight of benzene feed. The test was run for 14 days. The test protocol is summarized below:

TABLE 1

TEST PROTOCOL	
PARAMETER	VALUE
Temperature	400°C
Pressure	300 psig
Feed Rate	11.6 ml/min
Benzene LHSV	70 hr <sup>-1</sup>
Ethylene rate	291 st. ml/min
Benzene/ethylene	10/1 molar
Water rate	0.31 ml/min

The results of the test using ZSM-5 are summarized in Table 2.

TABLE 2

COMPOSITION OF EFFLUENT				
Test Duration (Days)	Ethylbenzene w %	Benzene wt %	M-Di-Ethylbenzene wt %	Conversion %
2	14.07	77.88	2.24	99.0
3	14.12	77.92	2.24	99.0
4	13.33	78.13	2.54	98.9
7	12.77	78.13	2.54	98.9
8	12.75	78.41	2.73	99.7
9	12.64	78.63	2.71	99.2
11	12.89	77.86	2.89	98.9
12	12.78	77.65	3.01	98.9
13	12.75	78.03	2.88	99.0

#### EXAMPLE 2

The catalyst used in Example 1 was regenerated in the usual manner until the stream was 100% air, with no exotherm present. The reactor was then heated to 500°C for twelve hours to complete the regeneration. The system was purged with a mixture of nitrogen gas and air until an exotherm passed through the reactor. The air content of the purge stream was slowly increased and the test repeated using the same procedures. The results are shown in Table 3, below.

TABLE 3

COMPOSITION OF EFFLUENT				
Test Duration (Days)	Ethylbenzene w %	Benzene wt %	M-Di-Ethylbenzene wt %	Conversion %
2	13.51	77.35	2.59	99.5
3	13.52	77.06	2.77	99.2
4	13.47	77.16	2.77	99.7
5	13.13	77.57	2.79	99.5
6	13.09	77.47	2.87	99.5

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TABLE 3 (continued)

COMPOSITION OF EFFLUENT					
	Test Duration (Days)	Ethylbenzene w %	Benzene wt %	M-Di-Ethylbenzene wt %	Conversion %
5	7	13.22	77.13	2.95	99.7
	8	14.15	76.22	2.96	99.8
	9	13.25	77.13	2.96	99.6
	10	13.19	77.01	2.98	99.6
	11	13.04	77.29	2.99	99.4
	12	12.84	77.48	2.99	99.2
	13	12.86	76.46	3.30	99.5

15

EXAMPLE 3

The procedure of Example 1 was used except that the catalyst was a silicalite having a crystallinity in the range of 76-93%, 64% monoclinicity, an average crystal size of 0.41 microns, a pore volume maxima for the binder at 1763 Angstroms and a Si/Al ratio of 114. The results are shown in Table 4.

TABLE 4

EFFLUENT COMPOSITION					
	Test Duration (Days)	Ethylbenzene w %	Benzene wt %	M-Di-Ethylbenzene wt %	Conversion %
25	1	13.74	79.14	2.29	99.3
	2	13.64	79.31	2.26	99.5
	3	13.68	79.24	2.28	99.5
	4	13.91	78.82	2.34	99.3
	5	13.56	79.29	2.31	99.3
	6	13.16	79.28	2.42	99.1
	7	14.13	76.57	2.97	99.0
30	8	13.07	78.10	2.80	98.4
	9	12.76	79.34	2.51	99.1
	10	12.36	79.87	2.45	99.5
	11	12.49	78.93	2.71	99.5
	12	12.46	78.66	2.80	98.9
	13	12.66	78.45	2.80	99.2
	14	12.34	78.84	2.77	98.8

50

EXAMPLE 4

ZSM-5 catalyst was loaded into a plant-scale alkylation reactor using standard sock loading procedures. The average loaded density of the catalyst material was 27.7 lb/ft<sup>3</sup>. The reactor was then operated at the following conditions:

55 Temperature: 350 - 450°C

Pressure: 200 - 500 psi

Benzene Feed Rate: 40,000 - 46,000 M lb/Day

Ethylene Rate: 800 - 1,800 M lb/Day

- 5 The benzene feed was sampled once per day and the water content determined. Percent conversion was also monitored daily.

While the present invention has been described in connection with the illustrated embodiments, it is not intended to limit the invention to the particular forms set forth, but on the contrary, it is intended to cover such alternatives, modifications, and equivalents as may be included in the spirit and scope of the invention as defined in the following claims.

10 Claims

1. A process for the alkylation of aromatic compounds, the steps comprising:

- 15 (a) supplying a feedstock containing an aromatic substrate into a reaction zone, the feedstock containing more than 100 ppm water;
- 20 (b) contacting the feedstock in the reaction zone with a silicalite catalyst formulated with a refractory oxide binder having a maximum pore size of 1,000-1,800 angstroms, said silicalite having from 70-100 percent monoclinic symmetry;
- 25 (c) supplying an alkylating agent to the reaction zone;
- (d) operating the reaction zone at temperature and pressure conditions to effect alkylation of the aromatic substrate by the alkylating agent; and
- 30 (e) recovering alkylated aromatic substrate from the reaction zone.

2. The method of Claim 1 wherein the feedstock contains 100-700 ppm water.

- 30 3. The method of Claim 1 wherein the aromatic substrate comprises benzene and the alkylating agent comprises ethylene.

- 35 4. The method of Claim 1 wherein the silicalite catalyst has an average crystal size of less than about 0.50 microns and a Si/Al atomic ratio of 50-500.

5. The method of Claim 4 wherein the silicalite catalyst has a sodium content of less than about 50 ppm.

- 40 6. The method of Claim 4 wherein 90% of the crystals of the silicalite catalyst have a particle size less than about 0.70 microns.

7. The method of Claim 1 wherein the temperature and pressure conditions include temperatures of from about 250°C to about 500°C and pressures of from about 200 psi to about 500 psi.

- 45 8. The method of Claim 1 wherein the feedstock also comprises polyalkylated aromatic compounds.

9. The method of Claim 8 wherein the polyalkylated aromatic compounds comprise substantially 10% of the feedstock.

- 50 10. A process of alkylation of aromatic compounds. the steps comprising:

- (a) supplying feedstock containing an aromatic substrate into a reaction zone;
- (b) injecting an effective amount of water into the reaction zone;
- 55 (c) contacting the feedstock with a ZSM-5 catalyst;
- (d) supplying an alkylating agent to the reaction zone;

(e) operating the reaction zone at temperature and pressure conditions to effect alkylation of the aromatic substrate by the alkylating agent; and

(f) recovering alkylated aromatic substrate from the reaction zone.

5

11. The process of Claim 10 wherein 700-100,000 ppm water based on the weight of the aromatic substrate is introduced into the reaction zone.

10  
12. The process of Claim 10 wherein 30,000 ppm water based on the weight of the aromatic substrate is introduced into the reaction zone.

13. The method of Claim 10 wherein the conversion conditions include a temperature of from about 250°C to about 500°C and a pressure of from about 200 psi to about 500 psi.

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14. The method of Claim 10 wherein the aromatic substrate is benzene and the alkylating agent is ethylene.

15. A method of alkylation comprising the steps of:

20  
20 (a) supplying the feedstock containing an aromatic substrate into a reaction zone;

(b) injecting water into the reaction zone;

25  
25 (c) contacting the feedstock with a silicalite catalyst, the silicalite catalyst having an average crystal size of less than about 0.50 microns, a Si/A1 atomic ratio in the range of about 50-500 and formulated with a refractory oxide binder having a maximum pore size in the rang of about 1000-1800 Angstroms;

(d) supplying an alkylating agent to the reaction zone;

30  
30 (e) operating the reaction zone at temperature and pressure conditions to effect alkylation of the aromatic substrate by the alkylating agent; and

(f) recovering alkylated aromatic substrate from the reaction zone.

35

16. The method of Claim 15 wherein the aromatic substrate comprises benzene and the alkylating agent comprises ethylene.

40  
40 17. The method of Claim 15 wherein the 90% of the crystals of the catalyst have a particle size of less than 0.70 microns.

45  
45 18. The method of Claim 15 wherein the catalyst has a sodium content of less than about 50 ppm.

19. The method of Claim 15 wherein the temperature and pressure conditions include a temperature from about 250°C to about 500°C and pressures from about 200 psi to about 500 psi.

50  
50 20. The method of Claim 15 wherein the amount of water employed is about 700 ppm to about 100,000 ppm based on the weight of the aromatic substrate.

21. The method of Claim 15 wherein the amount of water employed is about 30,000 ppm, based on the weight of the aromatic substrate.

55

FIG.1

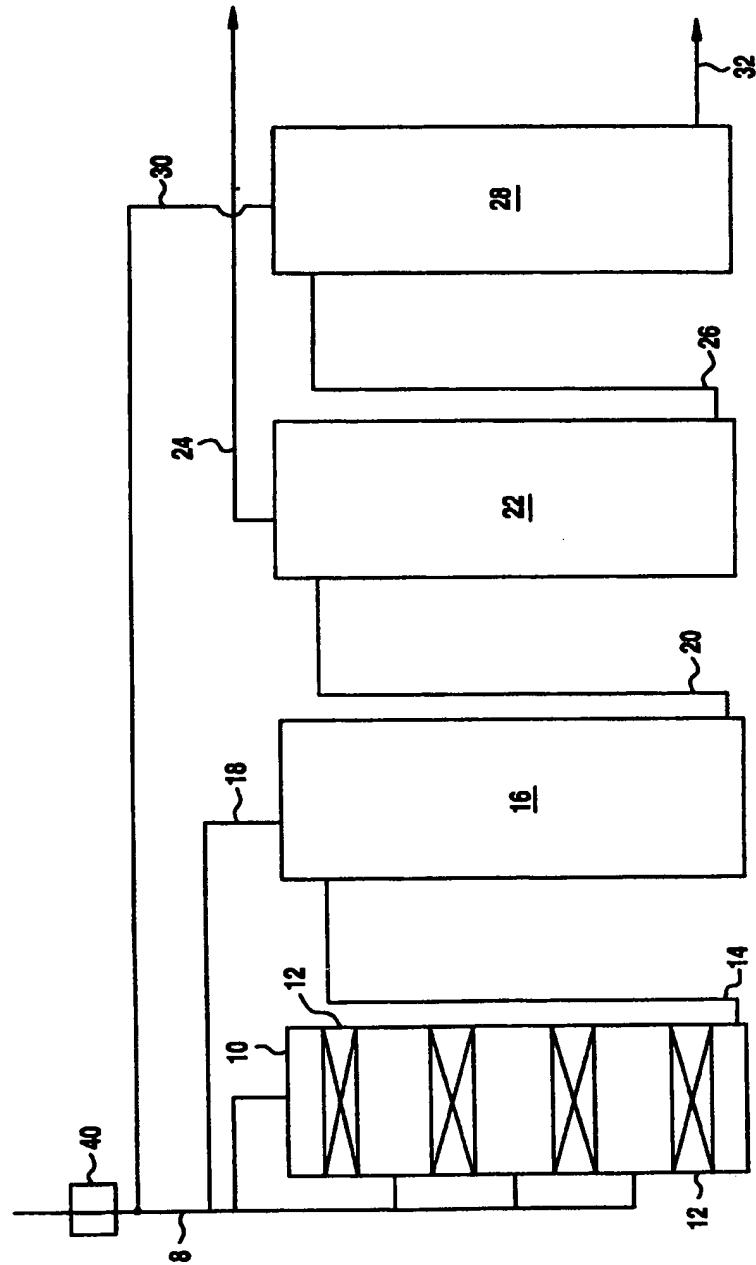


FIG.2

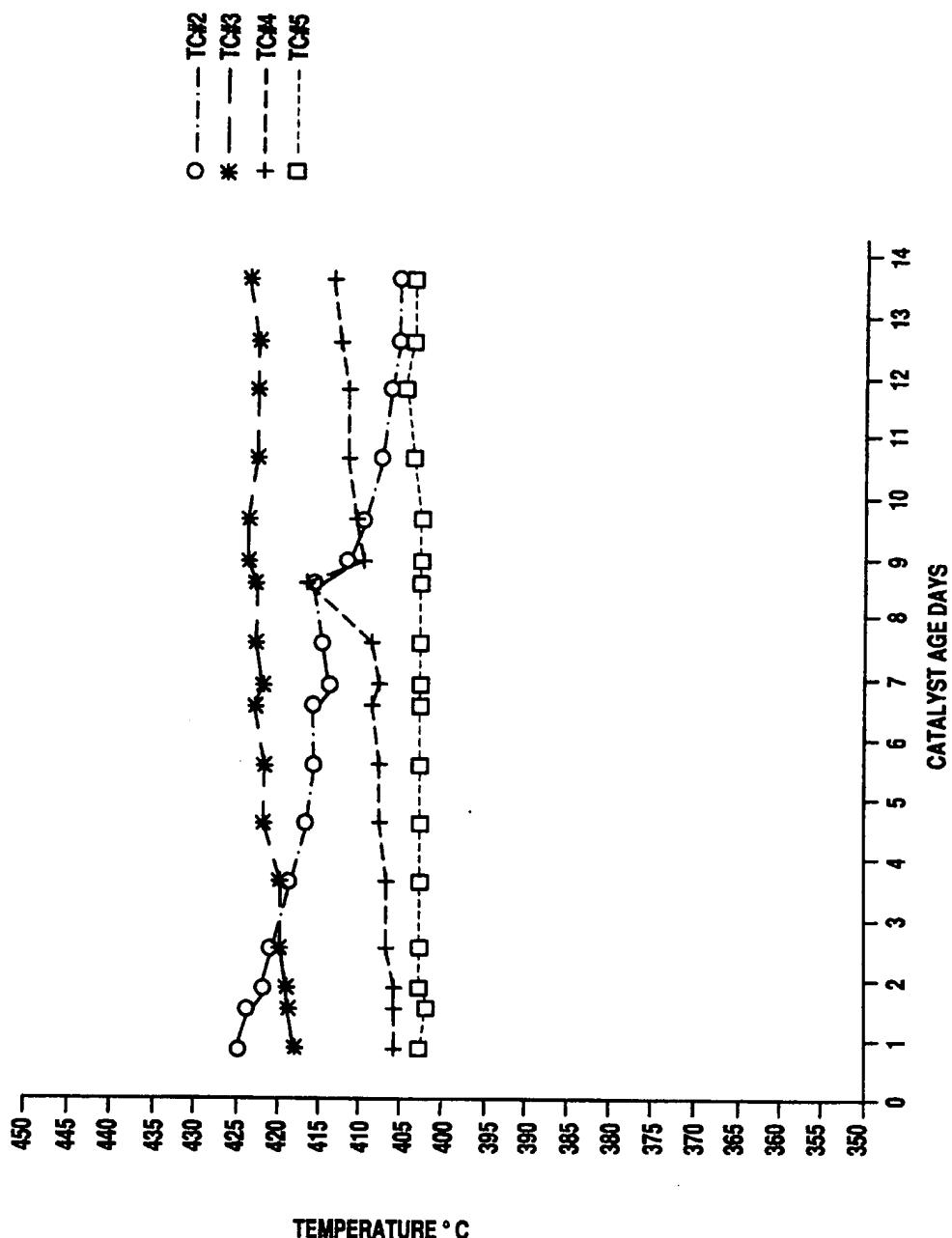


FIG.3

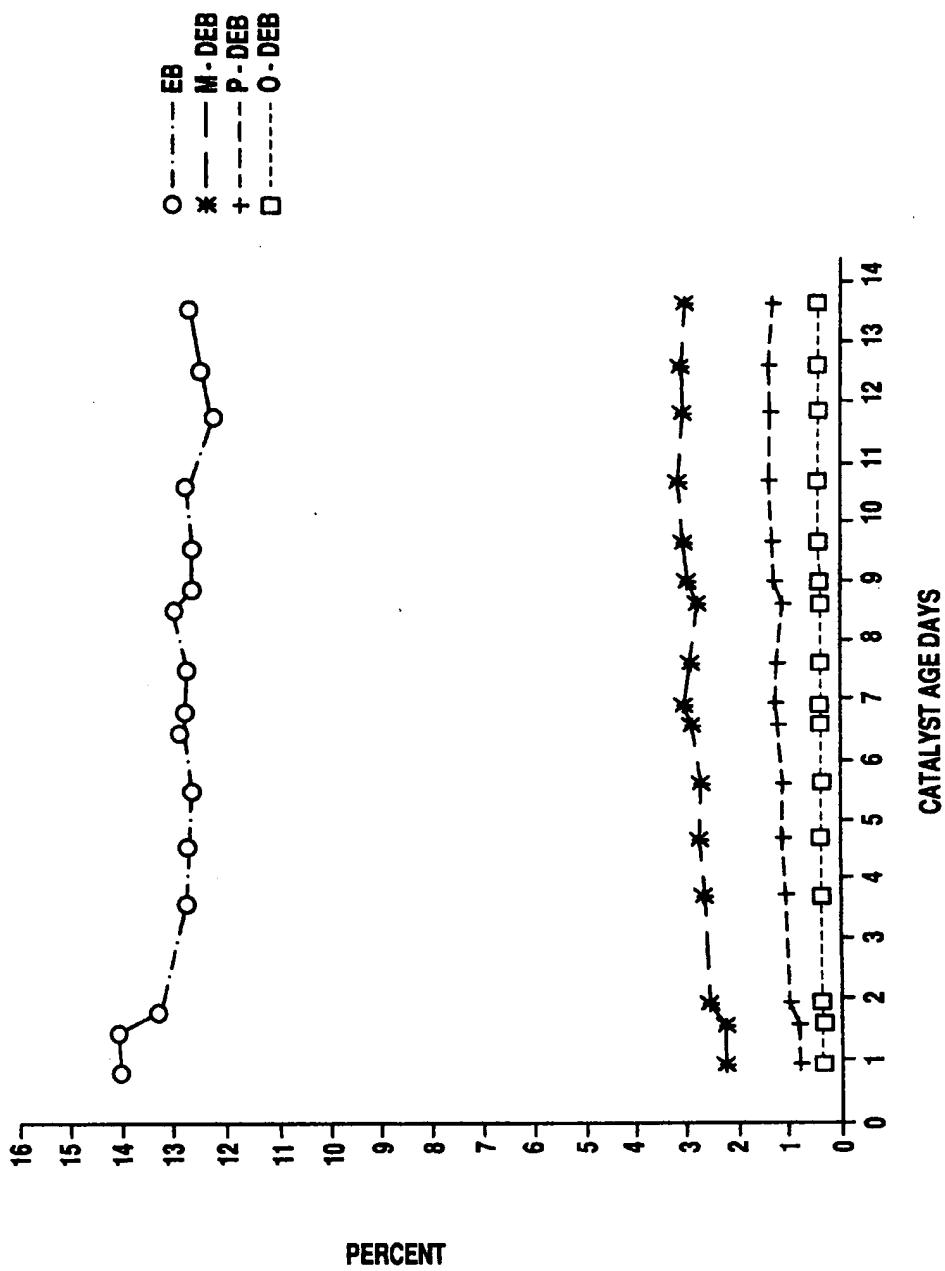


FIG.4

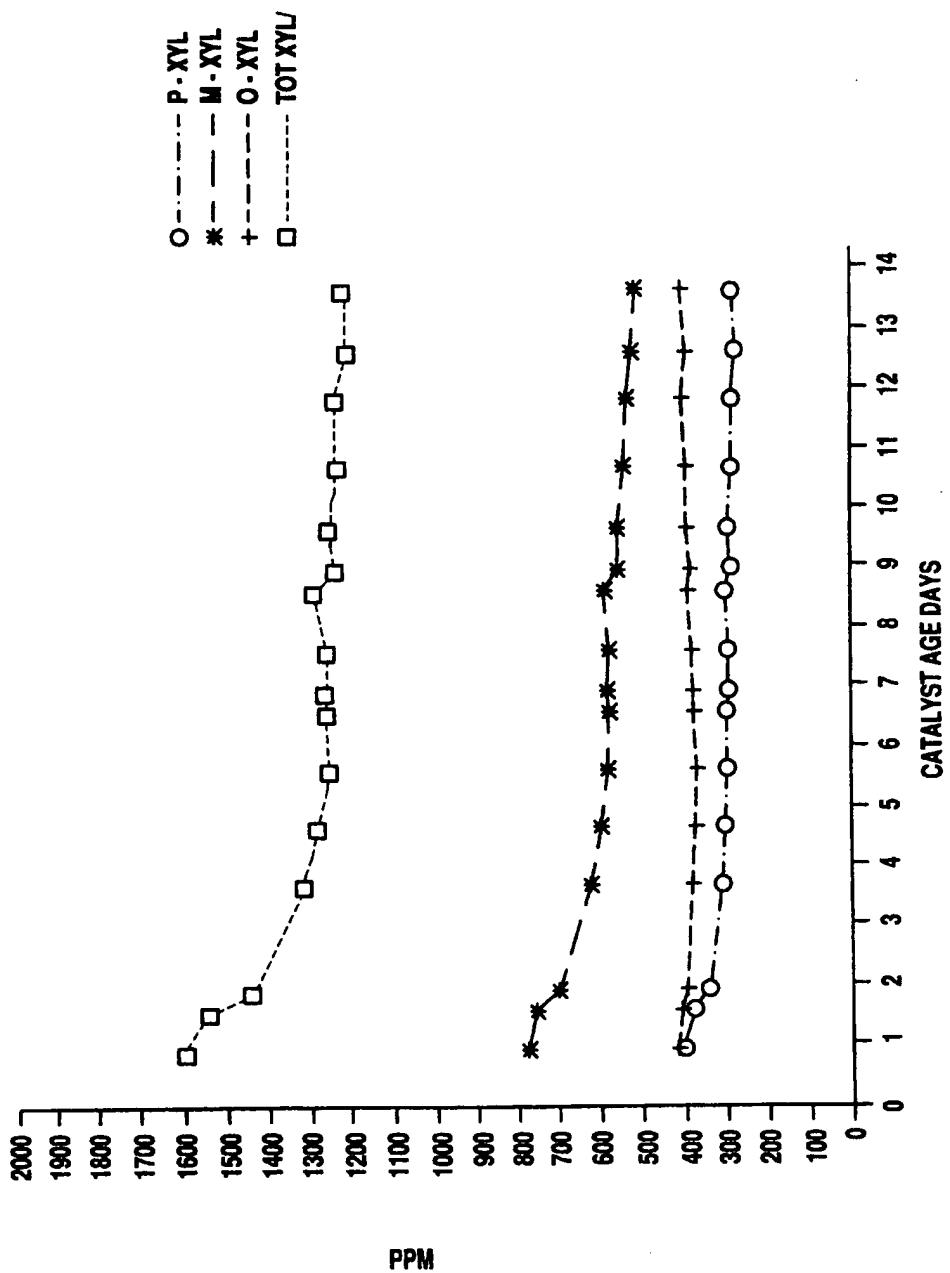


FIG.5

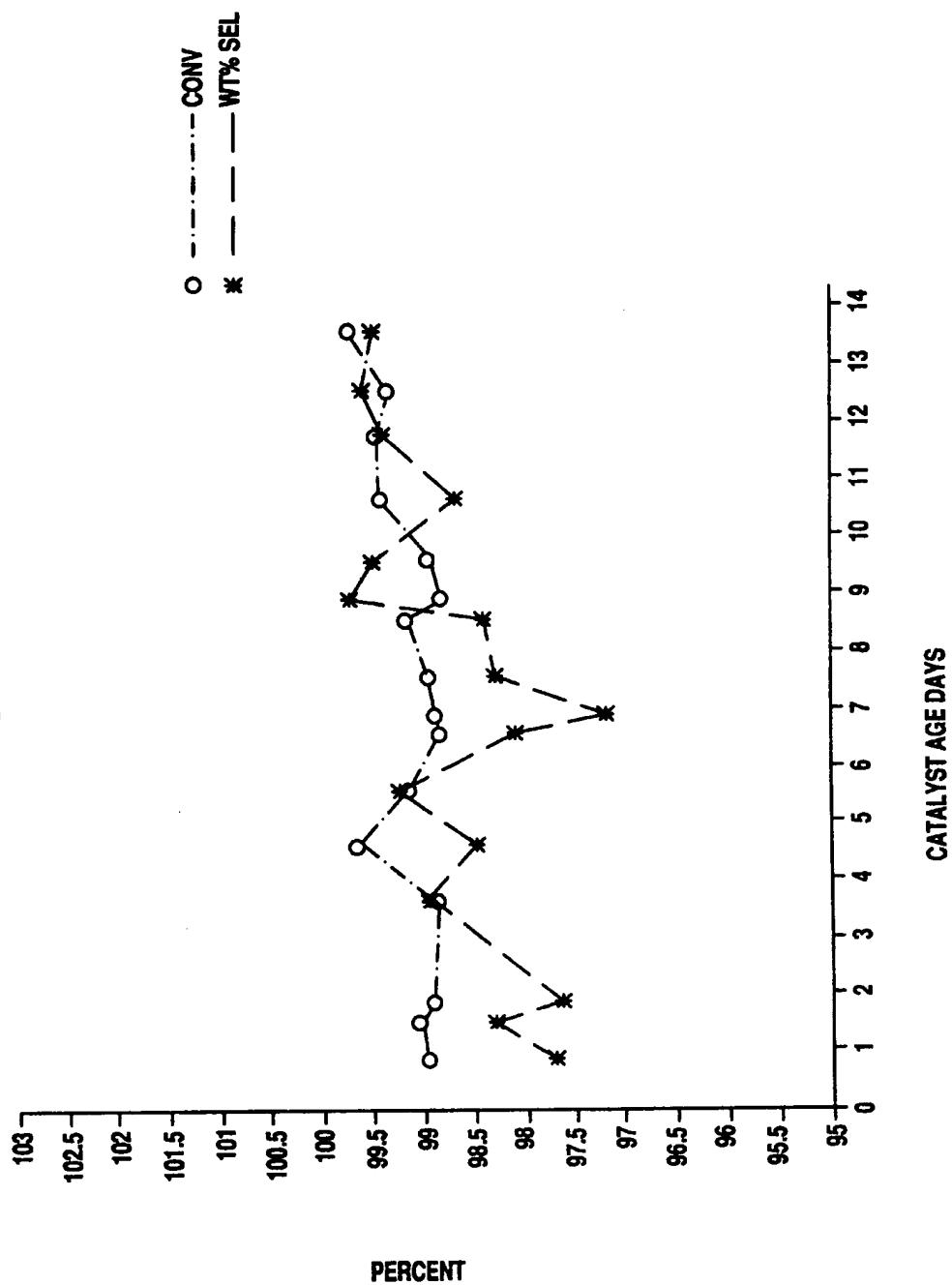


FIG. 6

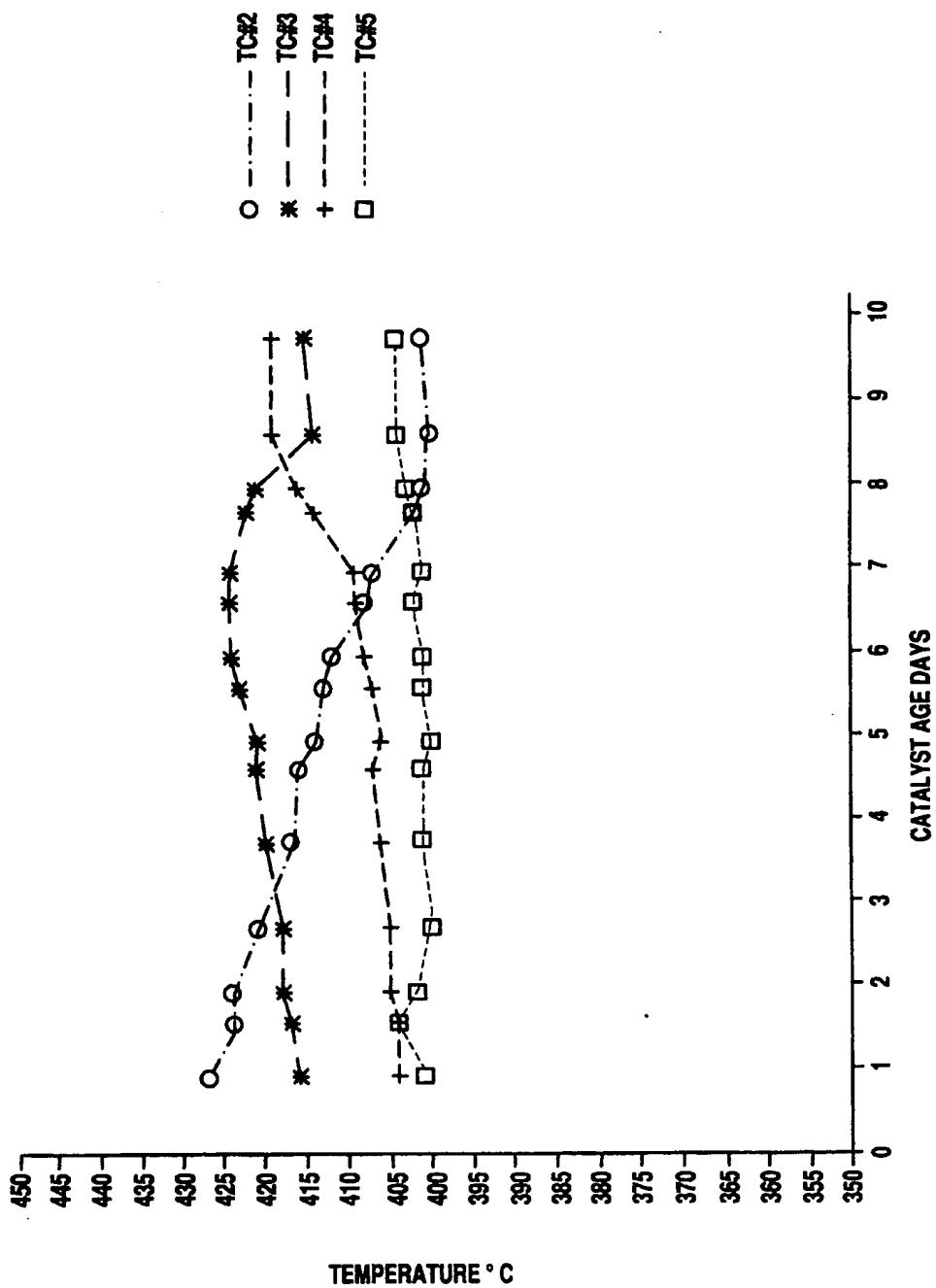


FIG. 7

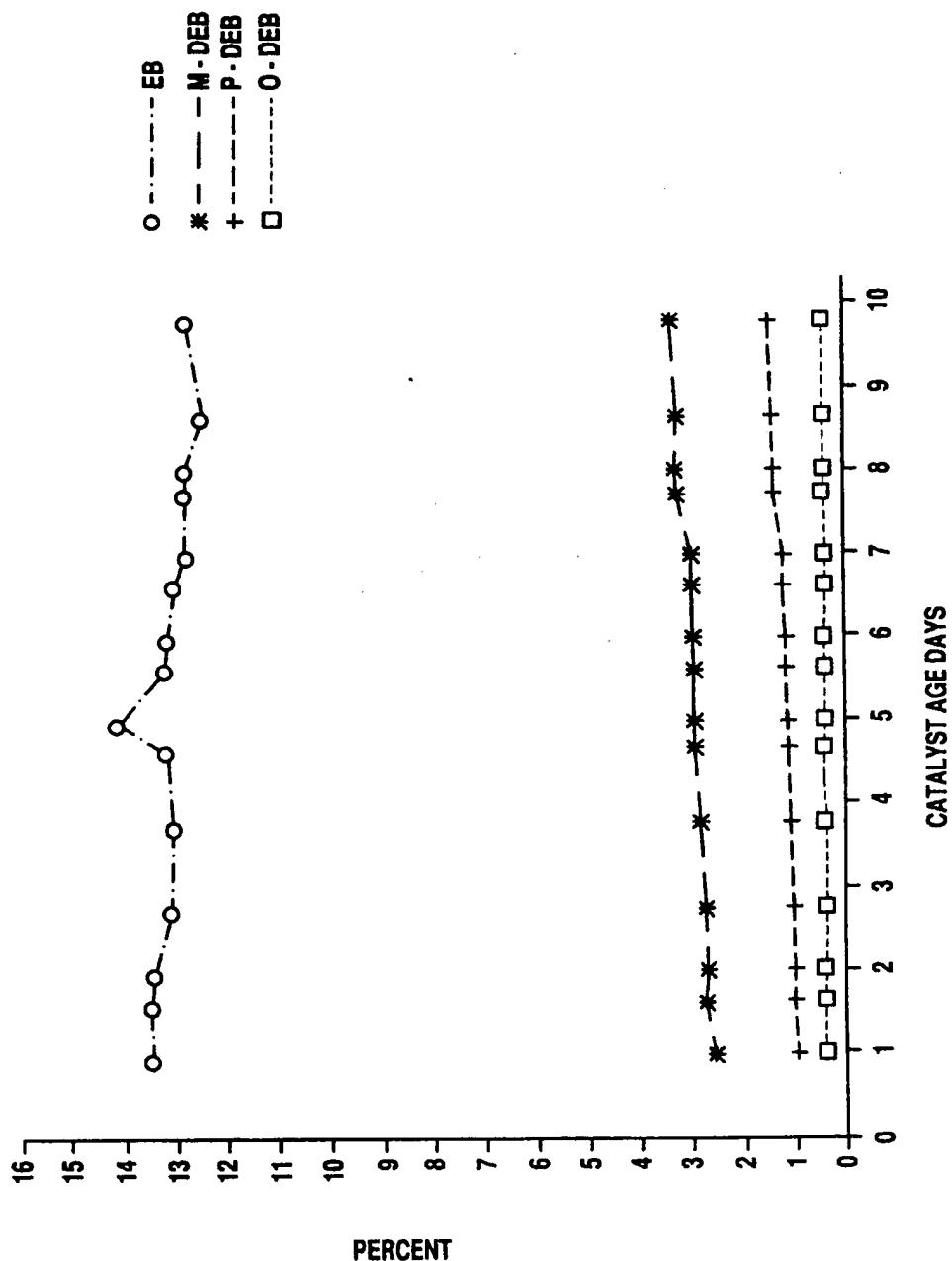


FIG.8

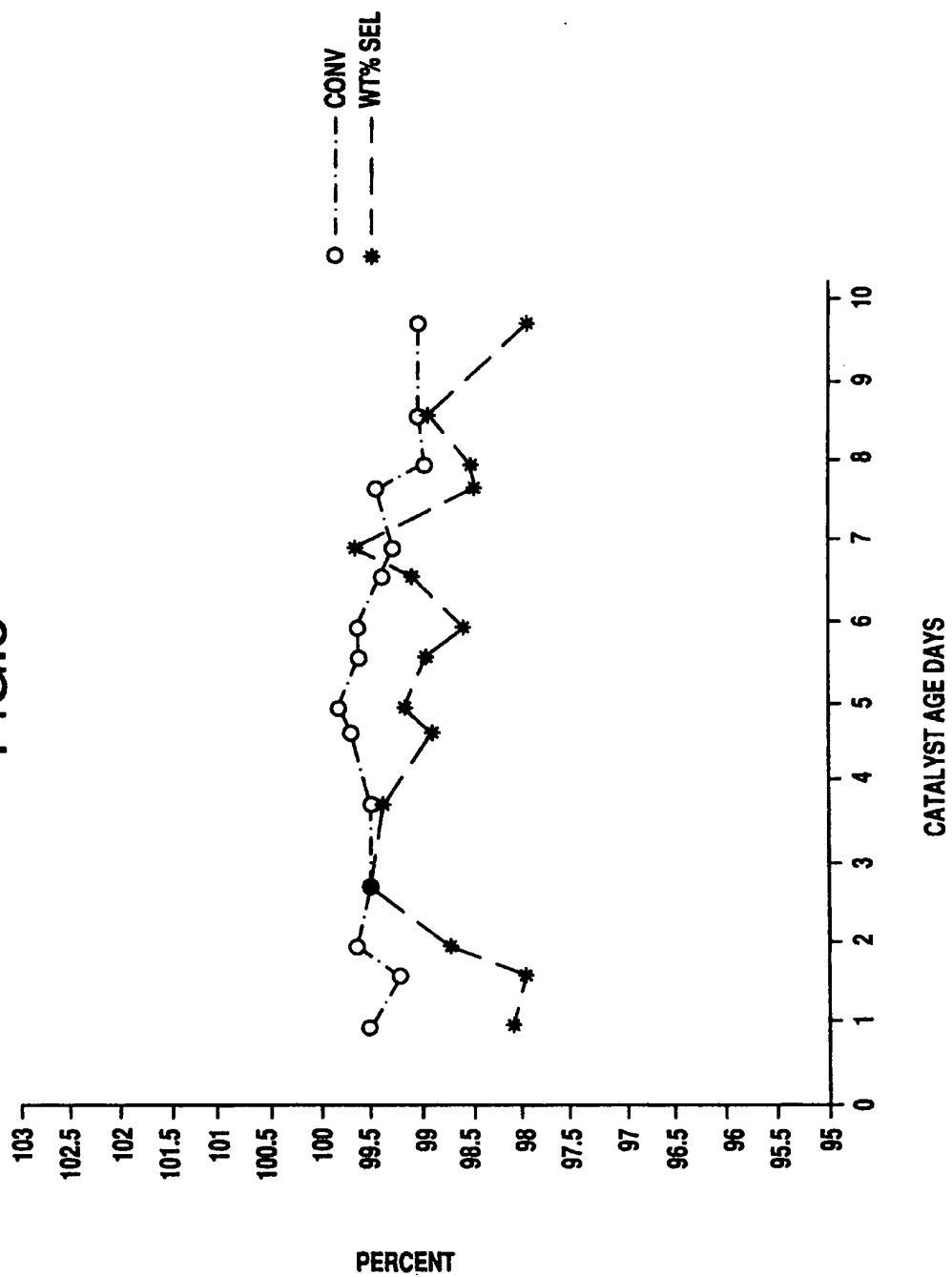


FIG. 9

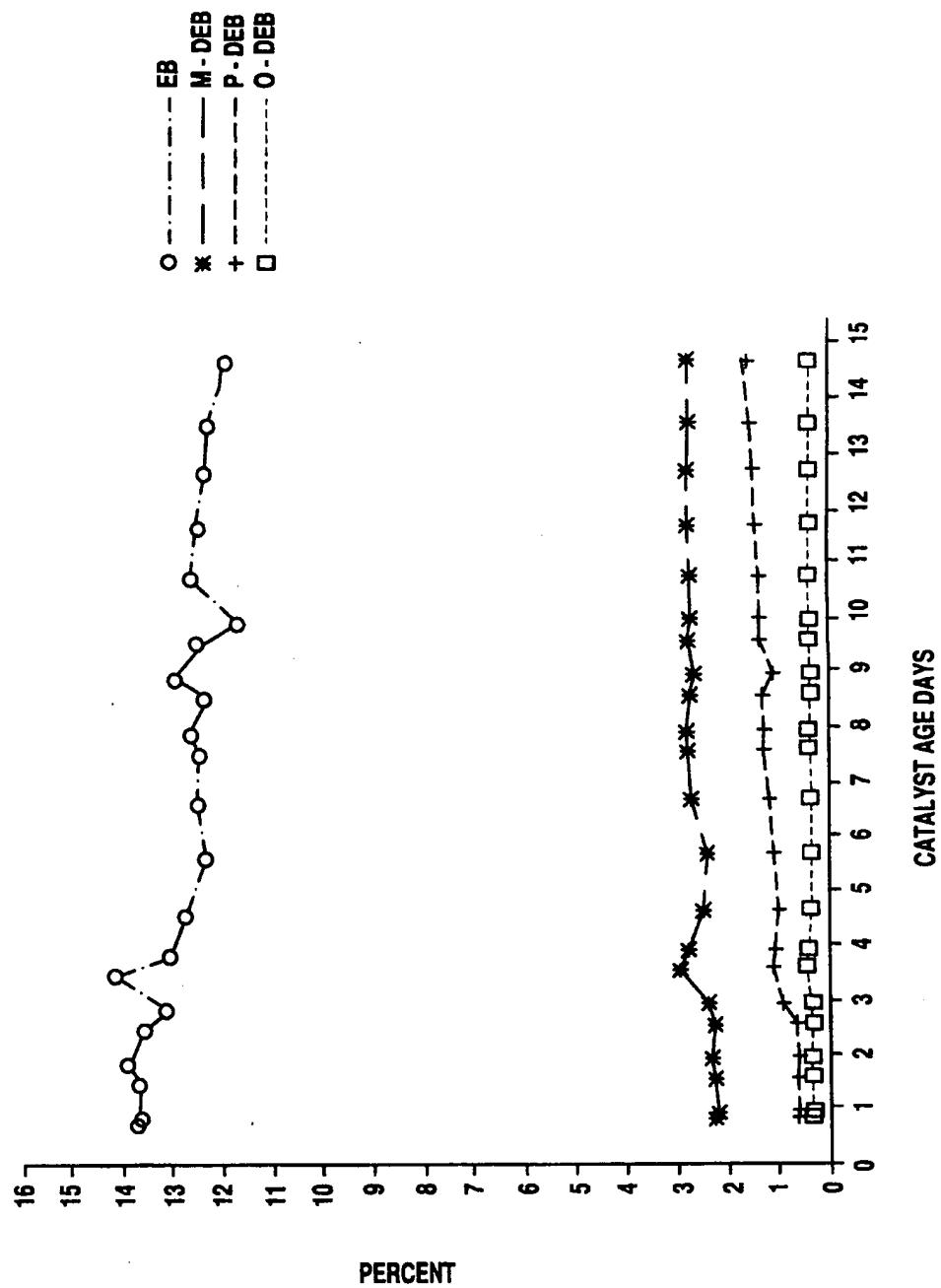


FIG.10

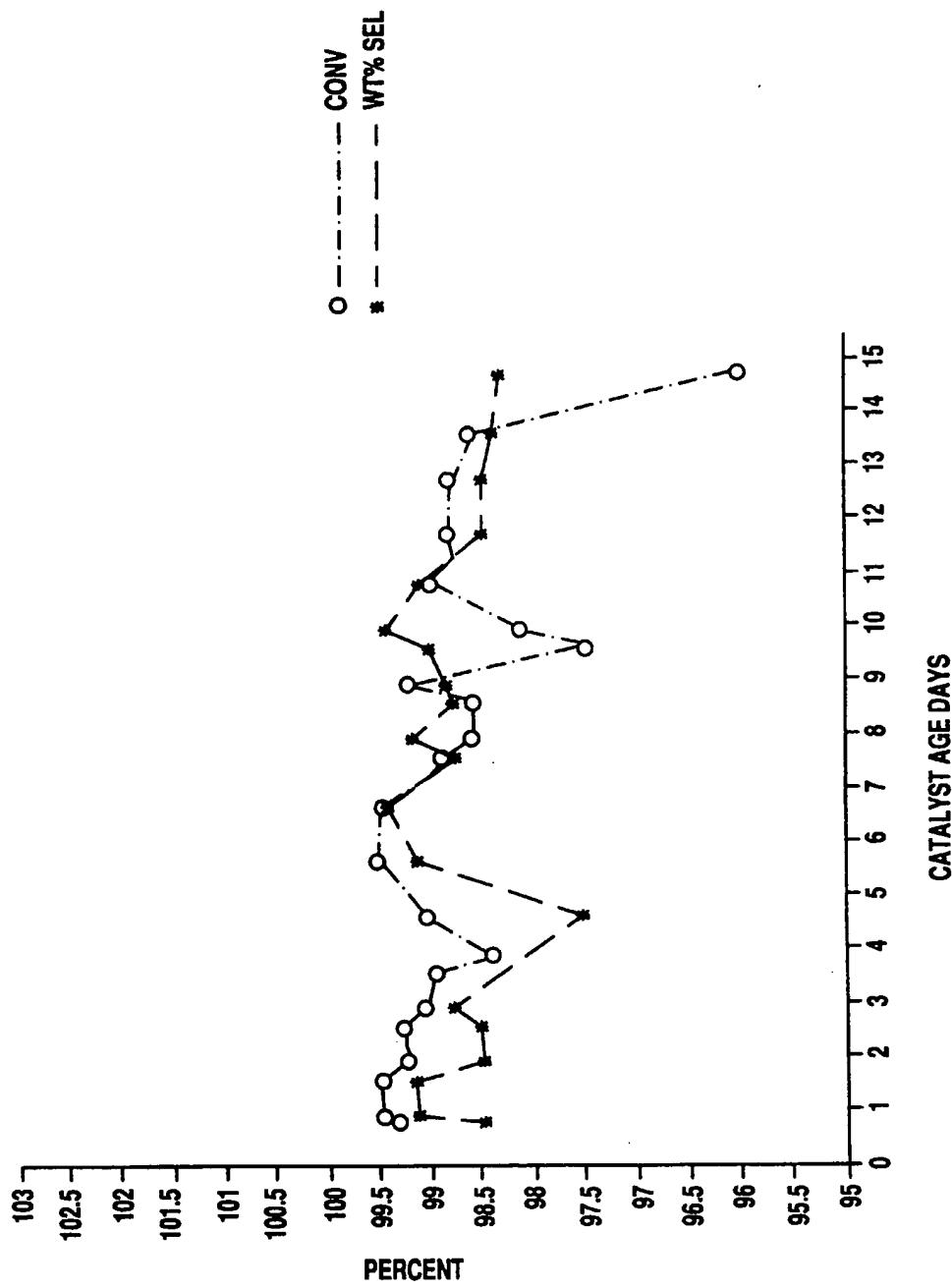
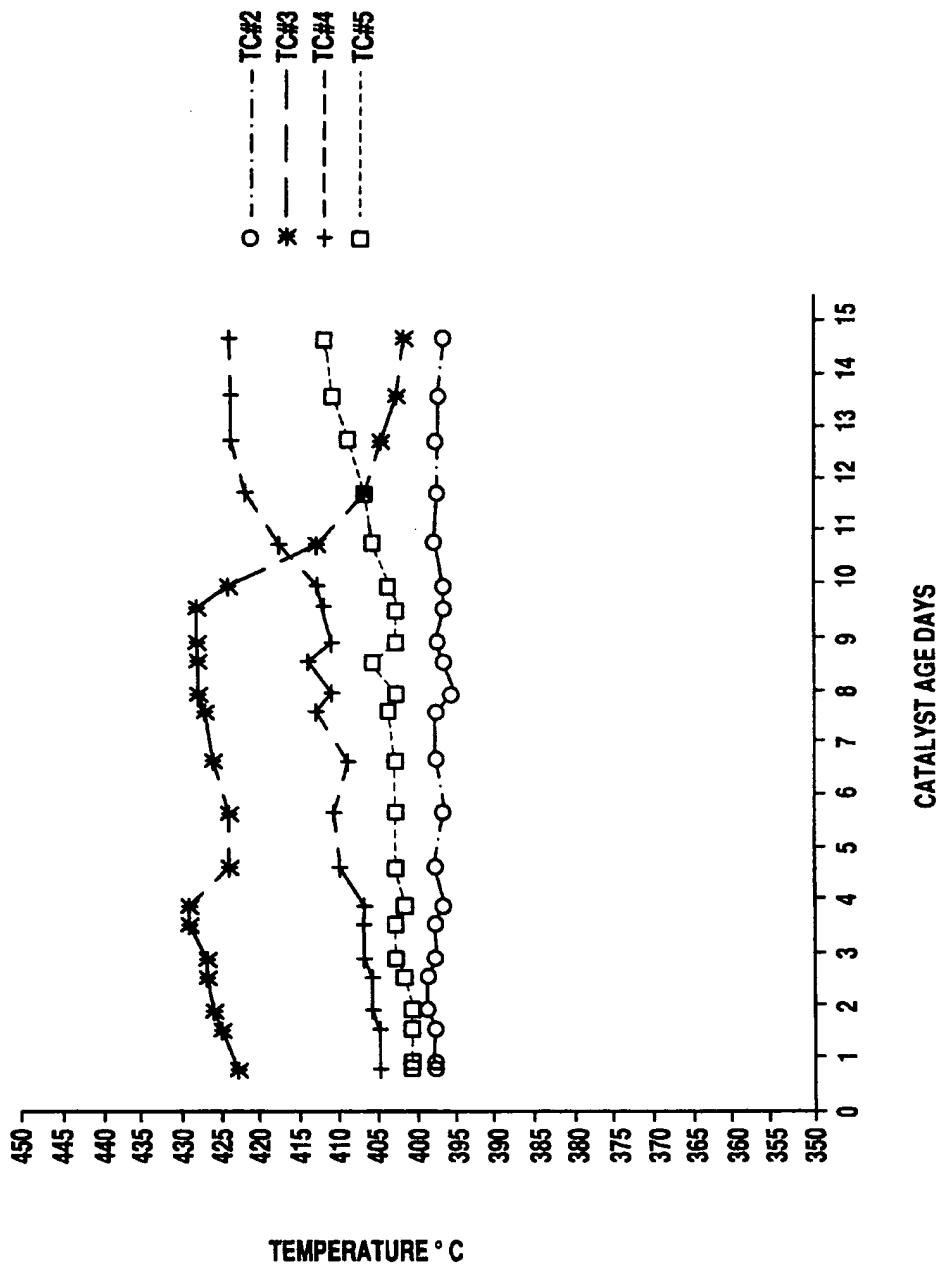
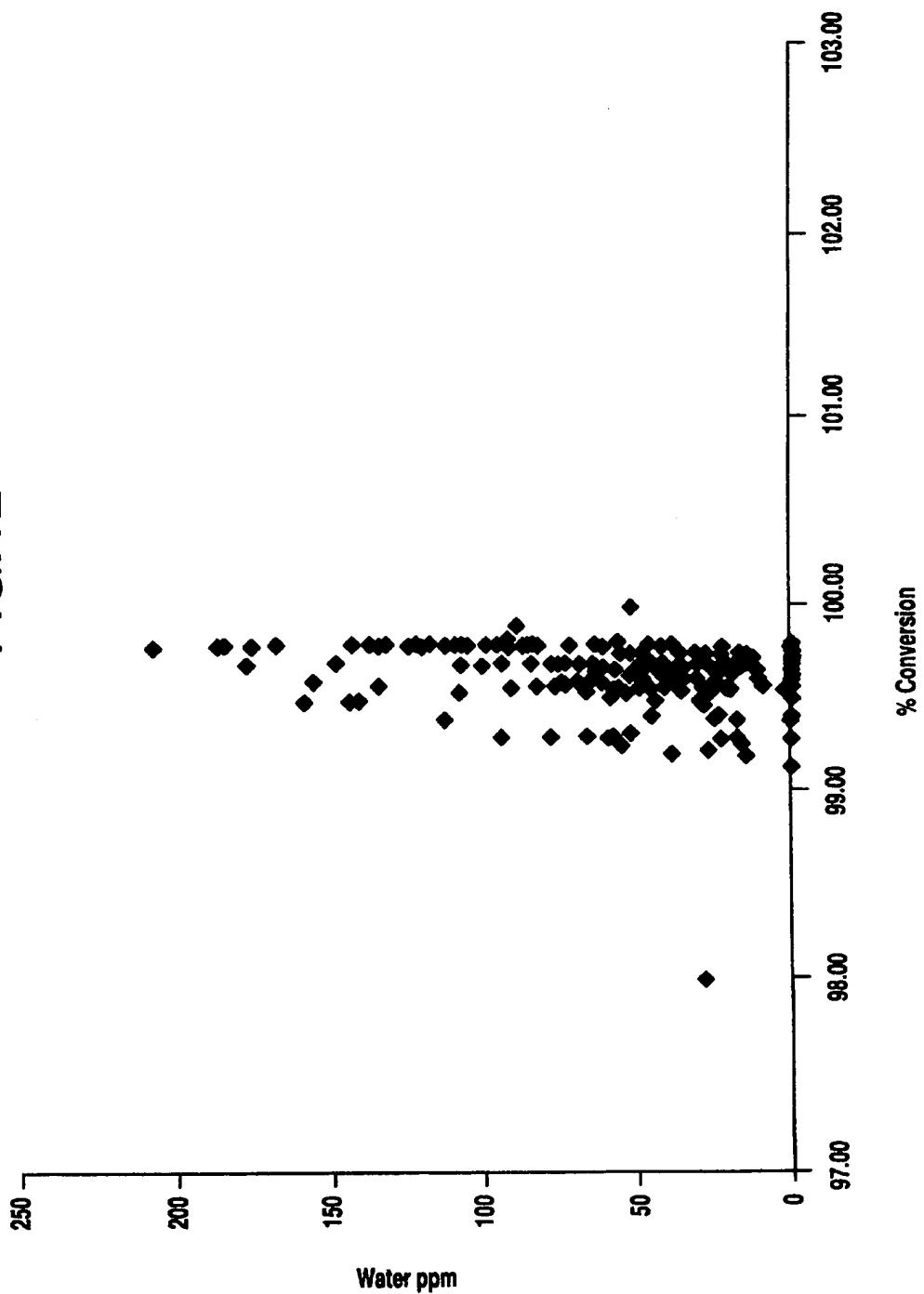


FIG.11



EP 0 842 914 A1

**FIG. 12**





European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number

EP 97 12 0167

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP 0 148 147 A (COSDEN TECHNOLOGY)  * claims * -----	1-8, 15-21	C07C2/66
TECHNICAL FIELDS SEARCHED (Int.Cl.6)			
C07C			
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	29 January 1998	Van Geyt, J	
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			